Optical Engineering
Prof. Shanti Battacharya
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture – 13
Lab 3 – OSLO

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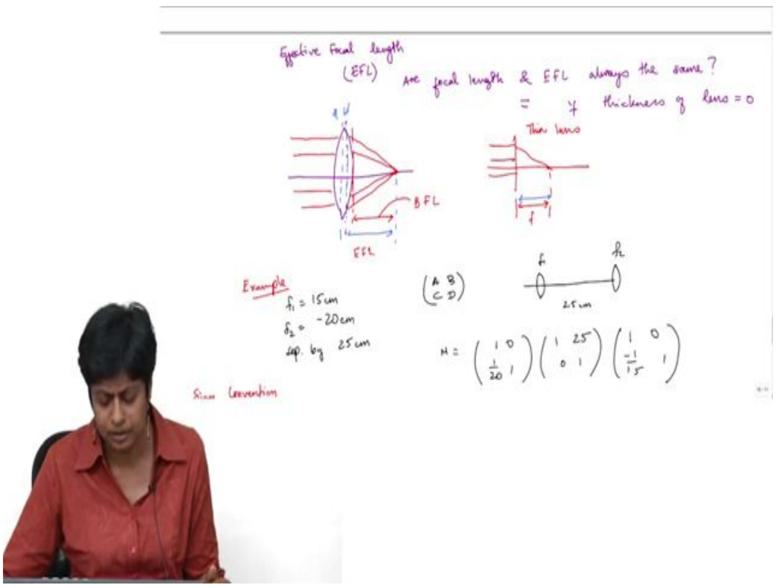

Good afternoon. So, we are here for the third Lab session and I just want to cover some of the points that we discussed in the earlier class because you are going to be using those concepts in today’s lab. So, we basically looked at systems which had more than one lens in them and we also said even a single lens if you cannot ignore the thickness you can think of it as having more dimensions to it and you approach those ideas through these planes called the principal plane.

So, we arrived at the way to calculate the locations using matrix methods ah. I need to correct one thing. So, this distance from the vertice is this is the back focal plane, let me just rewrite that and this distance from the principal plane. This will be your effective focal length. So, I had said that reversed ok.

Now, we have used this matrix method to arrive or calculate the locations of these planes and the usefulness of these planes is that I can now treat this entire system. It does not matter how many lenses or optical operations it has in it. I can now treat it in the same way I would treat a thin lens only making measurements now from the principal planes rather than from the vertices ok.

So, when I think of it now, how did we use the thin lens earlier? We had some rays we could trace through that thin lens very easily and there are similar rays you can try to trace through a system which has many optical operations in it and which you analyze through the principal planes.

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So, I want to introduce those different rays to you or points of different rays different points to you and for today's class I will introduce six points of interest six points some which seems familiar or similar to what you have done in the thin lens and we will just see those definitions in terms of the thick lens system. So, there are three pairs of points; the focal points, the principal points and the nodal points. You already are familiar with the first two pairs ok.

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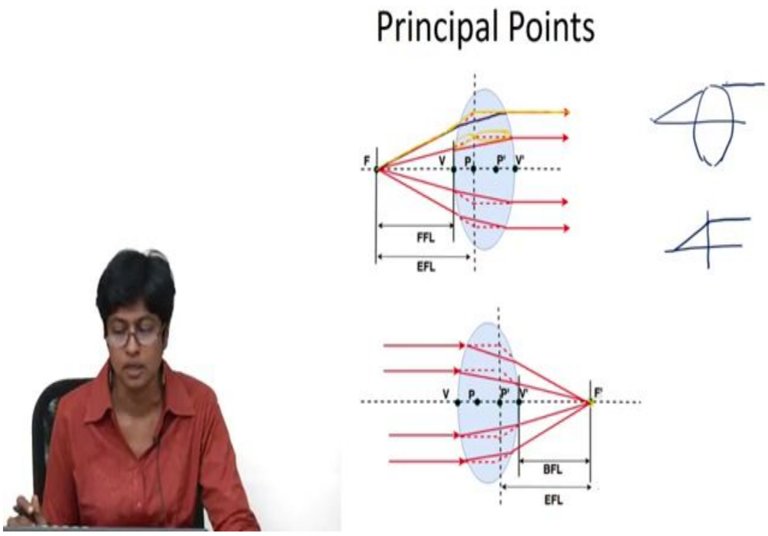

But let us just run through those definitions again. So, you know now how to calculate where the principal planes of a system occur. Given a system so, let in this case you have; obviously, a very thick lens not just a thick lens its a fat lens right and you have the location of the front focal plane and how do I use that? You can see from this diagram ray coming from the focal point, in our thin lens understanding we say it emerges from the system parallel to the system right. Anything if you had an object point at the source, you would send it out parallel after the lens and that is what you can see over.

Here what is very clearly demarcated, let me draw that for you is say you take the first ray. It is traced from the object point to the first surface of the thick lens. In this diagram, it very clearly shows you the refraction that happens within the thick lens right and then it bends such that it emerges parallel. The advantage of having the principal plane or the definition for us is I could win. So, for us the trick would be if I have a thick lens and I have a ray coming like this, how do I know where to draw it parallel over here? That is the difficulty. If it is a thin lens the ray the point at which it hits the lens, it is a that point that I draw it out like this.

With the thick lens I cannot do that because it has bent and traveled at an angle within that thickness. So, it emerges at a slightly different height and knowing where the principal planes are allows me to actually draw the point draw from the point at which the ray emerges because I will draw a straight line starting from here. I will draw this line straight all the way to the principal plane and then I will bend it and draw it parallel to the optical axis. That is not really what is happening, but the principal plane allows me to do this you know why because we have gone through that derivation.

So, within the thick lens system that is not really how the ray is traveling, but what is important to us is we know how we traveled up to the surface and this allows us to draw accurately where the ray emerges after the second interface. As you can see these regions have been drawn in a dashed line because they allow us to draw the final ray, but that is not actually what is happening within the surface. You would have to then take the refraction at those points into account.

But we are avoiding doing that exact refraction at each surface and just using this concept of the principal planes to accurately draw the incident ray and draw the exit ray ok. So, that should get clear to you and you can see here, this is the front focal distance and as I said it is from the vertex the effective focal length is from the principal plane. And similarly you have for the rays that come in parallel, they will get focused to the back focal plane or the back focal point and the distance from the lens to this point is the back focal length and the distance from the second principal plane to this point will be the effective focal length ok.

So, principal points are basically the points where the principal plane crosses the optical axis. We this you have seen in the morning class ok.

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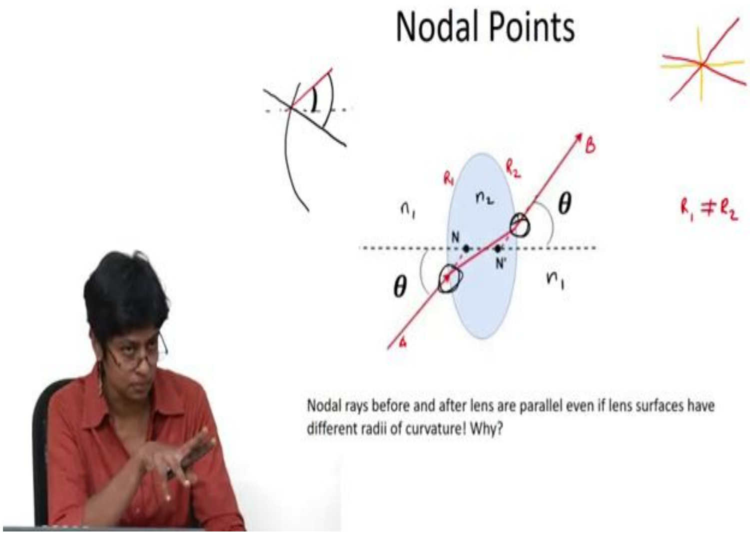

We also have a pair of points called the nodal points. Now, we know in a thin lens system if you had a thin lens drawn like this; if you were tracing array through the center of this lens does not matter what angle its coming in, it would go through would the center undeviated that is what we said for a lens going through the center of our thin lens.

So, whether it comes in at a shallow angle or at a larger angle, it always goes like a straight line through the center of the lens. I cannot do that anymore if I am considering a thickness, but I can trace a ray coming. So, that it is traveling straight, it hits some point if I were to continue it straight, but that is not what is happening, it is going to refract that ray goes through the center and then refracts again. So, these points N and N dash are called the nodal points of the system.

What can I say about this ray A and B? A and B, parallel rays. So, these rays and the emerging ray are parallel and they have gone through the center of this lens. If; however, I were to trace them undeviated, they would appear to come from two different points on the optical axis. We call those the nodal points and this is the equivalent of the ray going through the center of the lens in the thin lens case ok.

Now, what am I saying here? Here I am saying A and B parallel, but I could always have a thick lens where the radii of curvature R_1 and R_2 are not equal. So, let us say R_1 and R_2 are not equal may not be evident in this figure, but let us say I had a case where R_1 and R_2 are not equal. I am still going to say the nodal rays are parallel before and after. Why do you think that is so? How can they be parallel if the radii of curvature are different?

Do you expect the angle of refraction here to be the same as angle oh sorry the angle of refraction here? Let us say this is n1 n2 n1 do you expect the angle of refraction to be the same if R_1 and R_2 are one or the same. I am asking this because it brings across a very very important point. When I say parallel, we are talking about the angle with respect to the optical axis. If I talk about what is happening at this interface and what is happening at this interface of course, at those points I am going to apply Snell's law and Snell's law is always applied; the angles you measure are applied with respect to?

Student: (Refer Time: 10:16).

Which direction do you measure angles with respect to?

Student: Normal to.

Normal to the surface. So, we are not saying that the angles are the same angles when I consider the refracted angles, but you remember your refracted angle was always made up. We could always draw it if we had a curved surface like this and we had a ray coming through like this after refraction. And if this was normal to the surface, this was the optical axis; this is the angle of refraction; this angle is not the same as the angle in the object space.

What we were saying is this angle is the same right so, that is a distinction over there. When we say the emerging rays parallel to the incident ray so, the ray emerging from this thick lens system is parallel to the ray incident on this thick lens system. The node the rays that go through the nodal points are going to be parallel, this only means that we are saying this angle is the same in both cases; not the angle of refraction and that in angle of incidence ok.

So, this is with respect to the optical axis. It is a if you understand this point, it really goes a long way in understanding how these rays are defined and how you can therefore, trace them through a system ok. So, this is every system of course, will have two nodal points.

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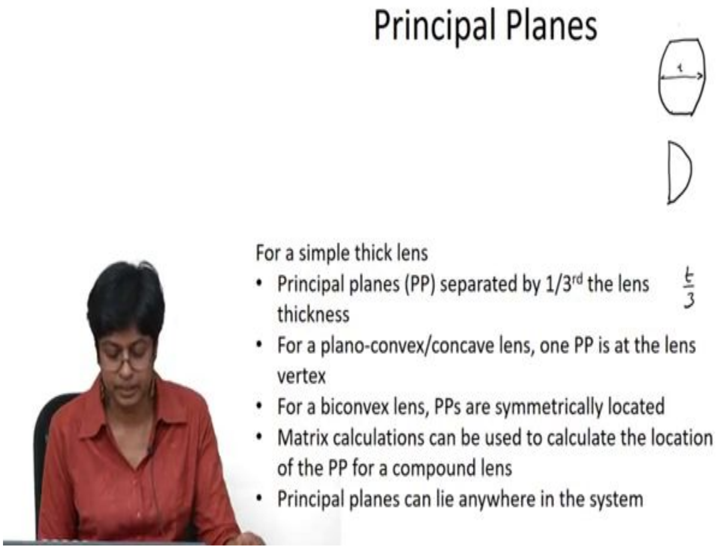

And I did not spend any time on the focal points, the focal points you are clear with. So, we have the principal points, the focal points and the nodal points ok. Now, if I take a simple thick lens, what do I mean by a simple thick lens? I am talking about a single lens, but has thickness. So, not a combination of lenses or not even lenses plus distances that is a compound lens. Here I cannot neglect the thickness of this lens, but it is a single lens with one medium kept between two in curved interface or with between two interfaces at least one of which has coverage ok.

This lens itself you can calculate the principal planes. Using exactly the same method, we used for this thick lens. You will be able to find out what is the abcd matrix and then using those values of a, b, c and d, you will be able to calculate the locations of the principal planes. For a simple thick lens the principal plane's rule of thumb is that the planes will be separated by roughly one-third the thickness of the lens.

So, if in this I have drawn here, this is the thickness of the lens and let us say it has thickness t the separation between. The principal planes will be roughly t by 3 ok. So, rule of thumb. If you have a lens which has a planar surface, one of the principal planes is always going to lie at the lens vertex ok. If you have a convex lens they are going to be symmetrically located and you can always use matrix calculations as we did in the morning to find out the location of the principal planes.

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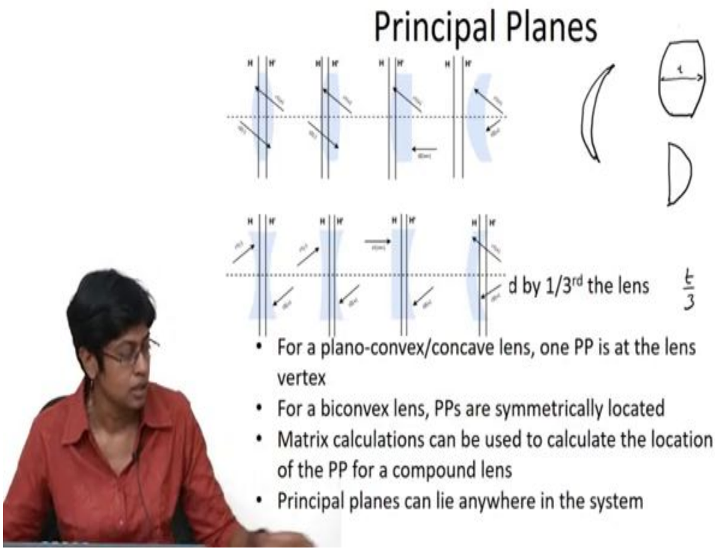

So, I have some images here for different simple lenses. So, simple thick lenses and for each of these cases, the principal planes have been located. So, you can see in the first picture, you have a biconvex and you have symmetrically located principal planes and the distance between them is roughly one third the overall thickness.

Here you have it's still by convex, but there are more curvatures approaching Plano convex because one surface is almost planar and you can see the location is no longer symmetrically located the principal planes have moved and one is getting almost to the vertex. When you actually take a Plano convex lens so; that means, one surface is flat the other is curved, you can see one of the principal planes is located over here at the vertex.

For this meniscus lens, we call this a meniscus lens. When both surfaces have curvature with the same sign, this is a meniscus lens. For such a lens, you can see that the principal planes lie outside the lens and this is the last point I have put here. Depending on your system the principal planes could lie anywhere and if you were trying to make a measurement or needed access to the principal planes, it could be sometimes that they lie within an optical lens within some part of your system. It may not be very accessible, you may not be able to make a measurement easily from that point right.

So, if for some reason you need to access the principal plane, you would have to look at your design and make sure that the principal planes are at accessible locations. So, I will not run through the lower set of figures there again for the more concave lenses and you can again see how these different points are validated if you look at different types of concave lenses ok.

So, with that background now you are ready for today's lab exercise and today's lab exercises, you in the last exercise you say you learned how to design a lens with a very specific focal length. In today's class you are going to now analyze thick lens systems ok. So, I just want to bring out some points in OSLO and then you will be ready to.

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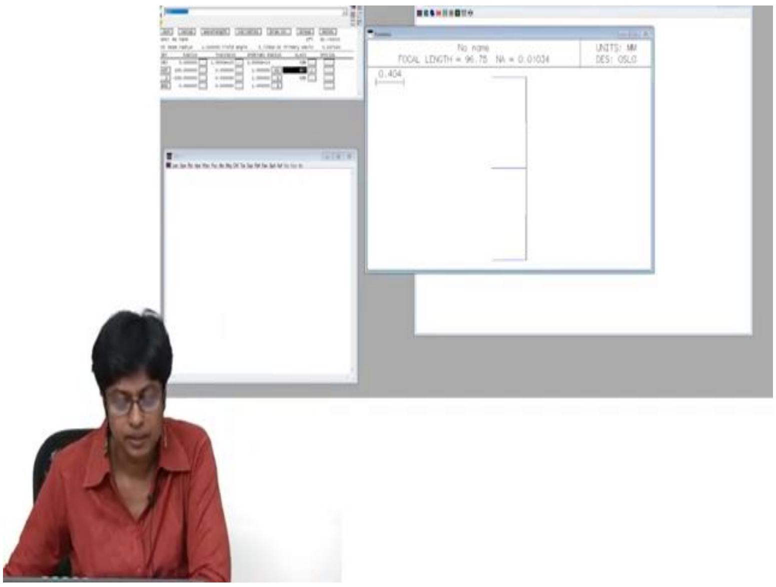

So, I have opened OSLO, I have a couple of rows here and let us just say I add some I am going to put a simple lens; a simple thick lens right.

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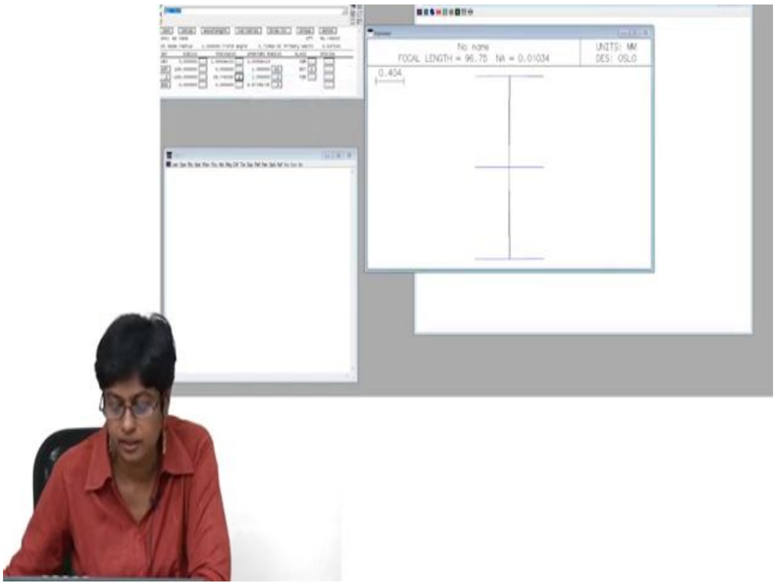

Now, let us solve. So, I am solving the axial ray height I wanted the next the image plane to be at where the axial ray height crosses is 0.

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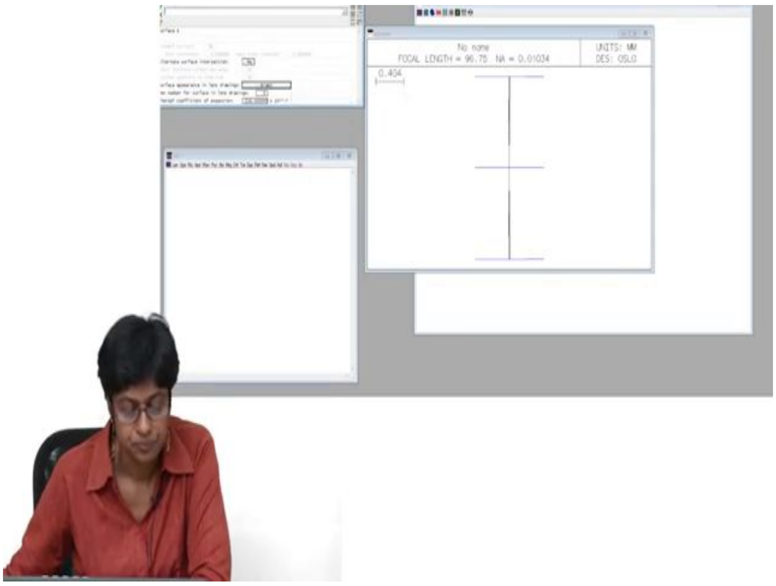

So, in other words the ray crosses the image axis and I want to see this surface, so that we can see that ok.

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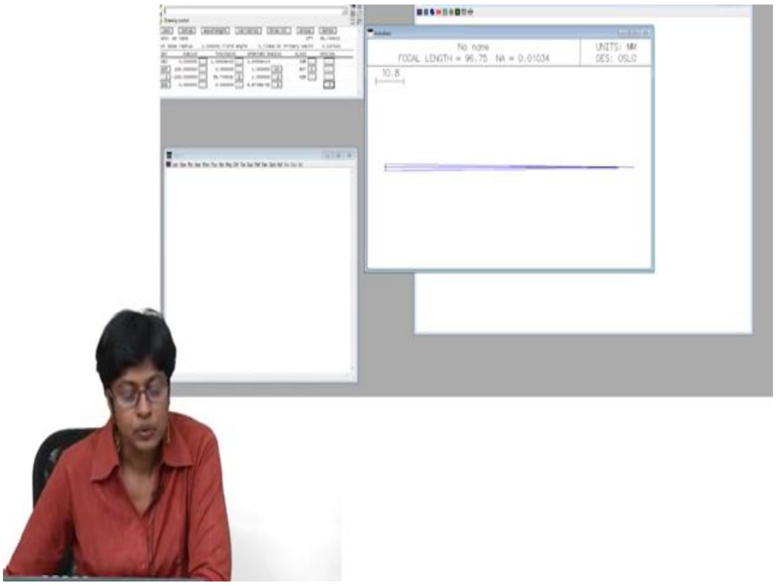

Now, you can see the effective focal length here that is what is shown over here. Now you know this is the distance from the second principal plane to the image point to the focal point, but in this case your lens has 0 thickness. So, if you look at the distance over here I have solved for where the ray height goes to 0. So, that is the from the vertex this distance gives you the distance from the vertex of the lens to where the ray crosses the axis, this gives you the effective focal length which is from the principal plane to where the ray is focused. But in this case these numbers are identical because the lens is a thin lens.

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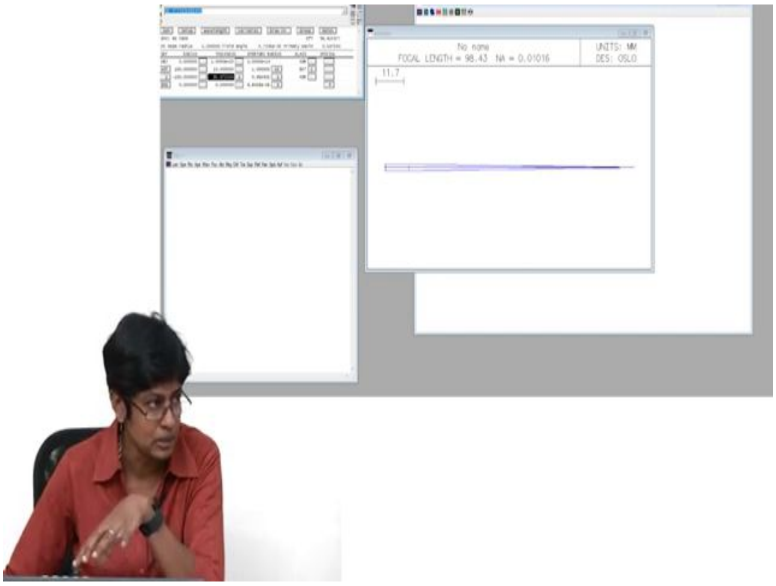

Now, let us say we go and give this lens some thickness ok. The moment you do that these numbers are going to change right. This is the distance from the surface, this is still the distance. What has not changed oh sorry what actually would have changed this you have changed the system because you have changed the thickness. So, the location of the principal plane is going to change, but you now have the effective focal length measured from the second principal plane and this is the distance from the vertex of the length and. So, now, you have a difference in those numbers ok.

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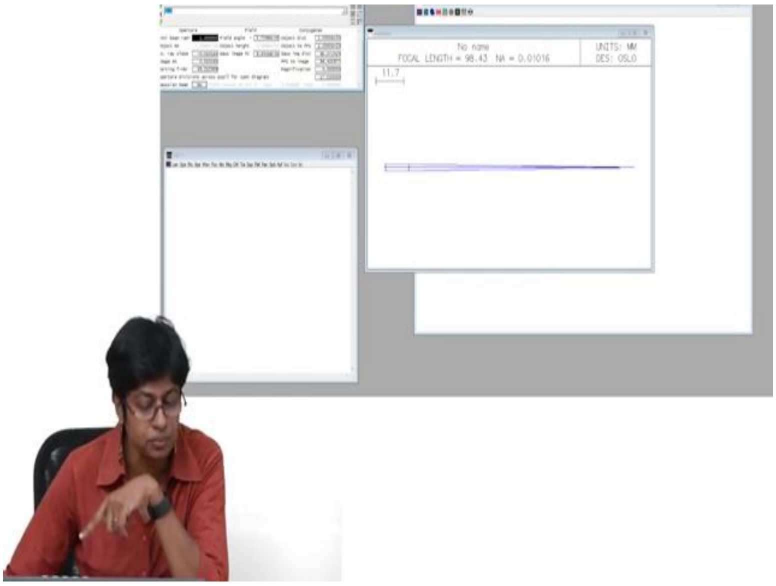

Now, this is a very simple system. You could always have a more complicated system and you could always and you may not always be looking at your you may not always have a parallel set of rays coming in, your race could be coming in from somewhere else. So, if you want to look at the location of a principal plane, you need to go to set up and look at this. So, this gives you PP 2 is the second principal plane and this is the distance from the second principal plane to the image position ok.

So, you get that information from this command here something else. Another point that I want you to think about in one of the earlier lab classes we asked you to find out though maybe was the last class, you were asked to find out the focal length or design the system to have a specific focal length and you were asked to use an operand. And which operand do you ask to use?

Student: PU operand.

The PU operand.

What is the PU operand? PU is an angle, angle of what?

Student: Axial.

It is the axial ray. So, I can define it at any interface and we say choose.

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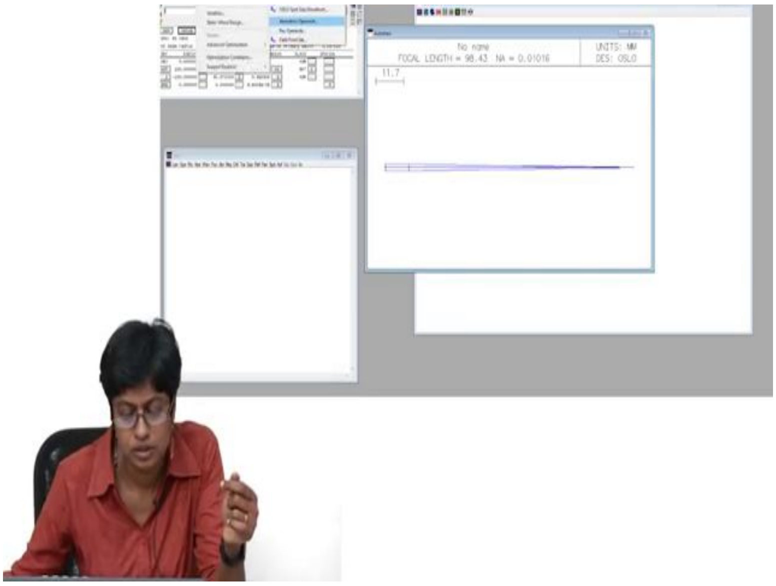

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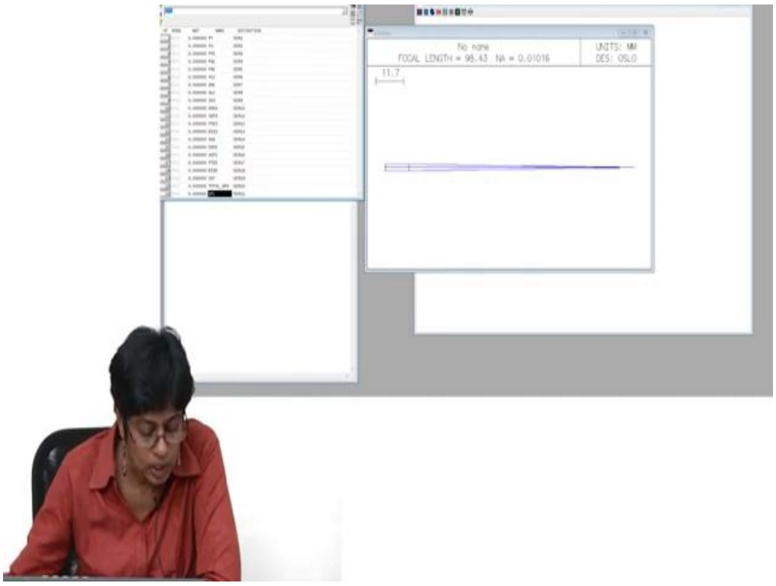

So, what would we do? We went to generate error functions and aberration operands we wanted PU. So, we changed the weight of this to one and then if you choose this and you choose some parameters variable. OSLO will try to minimize this to 0. Here we did not want the angle to be 0, we wanted the angle to have a certain value.

So, you add whatever or subtract whatever needs to be. So, that total sum goes to - right. So, you are controlling the angle. So, now, it does not matter when I am trying to get the focal length of a system, I am trying to design the focal length of a system. It does not matter whether I use the PU operand or the effective focal length operand. If I am designing a thin lens the moment I am designing a thick lens does it not matter, can I use either PU or effective focal length is it exactly the same thing ok?.

You say no, it is not the same thing and of course, I am going to ask you why it is not the same thing. You are correct, it is not the same thing. Why is it not the same thing? Go and think about what is the difference between using the PU operand and using the effective focal length, how that understanding means you have really understood your chief ray, your axial ray and your principal points ok.

So, I want you to think about that; that is a question I am leaving you with and play around with OSLO. If you need to help you answer that question is designing a lens with a specific focal length, the same is can you say the procedure to design a lens with a specific focal length the same whether I use the PU operand or the effective focal length operand. And if not, what is the difference between these operands?

Student: (Refer Time: 22:07).

See when I go to operands, I do not know if you noticed when I go here I have the I can use this, but there is also an effective focal length over here right and I did not ask you to use this last one in because I wanted to understand how I use the axial ray. I wanted you to use the axial ray and figure it out, but I could. In fact, you might think that I might want to use effective focal length. But I want you to think about it and tell me why. Another point just this is more out of how to use OSLO and it is easier to use OSLO.

When you are first setting up your operands, you go through the process that I just did. So, you go to optimize generated error function aberration operands. When you do this it will always clean the slate. Anything you had defined earlier is cleared and it gives you this right. So, let us say we choose PU and we want to reduce some aberration. So, we choose so, we have given all of these weight one; that means, these are the operands; we want to work with you and accept this.

Now, say you want to go back and make some change; you do not have to go back through that then you just go to operands and it will give you back those operands with whatever entries you had already made. If you go back the way we had the first time, it will give you a clean slate; everything you have defined would be wiped away. So, if you want to add or edit something, you just go back this way and then you do not have to re enter all the information. Only go make that specific change that you need to make.

Student: (Refer Time: 23:32) When we use the principal axis instead of.

The effective focal length uses the principal axis, you are saying define or change some parameter somewhere.

Student: (Refer Time: 23:46).

Yes. So, he is the one you are attempting to answer the question right. So, the difference is that when I say use the effective focal length, we are saying I chose curvature of one of the surfaces as the variable with which to change focal length of the system. I am saying change the curvature such that the effective focal length at the focal point lies this distance away from the principal plane. Whereas, when I say axial ray I am saying change the curvature so that the ray bends such that it crosses the axis at this distance away right. They need not be the same thing if the lenses are thick.

So, it is not exactly the same thing depending on what you want to do, depends on what your goal is, but it is not exactly the same thing ok. So, with that you can start today's exercise. Today's exercise is basically working with thick lenses and how you can pull out relevant information about thick lenses from OSLO and how you can design certain thick lenses.